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Monitoring population dynamics and survival of Northern Crested Newts (*Triturus cristatus*) for 19 years at a pond in Central Europe

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Abstract. A population of Northern crested newts, *Triturus cristatus,* was studied for 19 consecutive years (1998–2016) using individual recognition allowing the quantification of population dynamics and survival rates. Starting with a relatively high estimated number of adults (251 ± 55) and a long stable phase (144 ± 25) the population dropped six-fold (39 ± 10) by the end of the study. The population failed to recruit in nine years including a reproduction failure over four consecutive years of the 19-year study period. The yearly adult survival ranged from 18 to 98% with no differences between the sexes. Likely related to relative favourable survival rates of individuals older than 4+ of age and adult longevity of more than 16 years the population persisted. More long-term studies are urgently needed to assess how population dynamics are subject to local environmental factors or demographic patterns of the population itself.

Key words. Amphibia, Urodela, newts, *Triturus*, monitoring, capture-recapture, recruitment, persistence.

Introduction

For long it has been demonstrated that the Northern crested newt, *Triturus cristatus,* to be the rarest of the four newt species native in Central Europe (e.g., Feldmann 1981, Grosse & Günther 1996, Duguet & Melki 2003, Arntzen & Smit 2009). Throughout its distribution range *T. cristatus* usually lives syntopically with various other amphibian species including newts. Because mostly lowland distributed Northern crested newts have highly demanding habitat requirements in terms of pond size, sustainability, vegetation or sun exposure different from other palaearctic newts they are more vulnerable (Arntzen et al. 2009). Declines of Northern crested newts and its relatives throughout Europe resulted into strict EU legislation-based protection measures that member states are required to implement.

Long-term studies are necessary to judge the persistence of local amphibian populations (e.g., Arntzen & Teunis 1993, Kuhn 1998, Ortmann 2009, Griffiths et al. 2010) and they are especially wanted for vulnerable amphibians such as Northern crested newts while outcomes directly influence species conservation. However long-term monitoring programs may be difficult to carry out, are personal intensive and financially expensive (e.g., van de Crommenacker et al. 2015, Taig-Johnston et al. 2017). Also monitoring requires repeated and standardised observations of abundance over a long time period and the use of effective albeit standard methodology enabling the detection of changes in animal numbers (Hallmann et al. 2017). Up to now only a handful of studies on longer time-series analysis (> 10 yrs) have been applied to salamanders (e.g., Schmidt et al. 2005, Salvidio 2007, Griffiths et al. 2010, Montori et al. 2012, Lau et al. 2017, Mori et al. 2017, Homan et al. 2018). Because of their persistent ventral pattern allowing long-term individual recognition (e.g., Hagström 1973, Arntzen & Teunis 1993, Mori et al. 2017) most crested newt species (genus *Triturus*) can be perfectly used for monitoring programs employing capture and recapture methodology.

Here we present the long-term dynamics of a population of Northern crested newts *Triturus cristatus* from Northwestern Germany including an assessment of survival based on capture-mark-recapture data collected over 19 consecutive years. We compare the long-term population data with those available from other crested newt sites across Europe.

Material and methods

Study site

The study was carried out continuously from 1998 to 2016 at a pond situated north of Dorsten (district Recklinghausen, state of North Rhine-Westphalia, Germany, 51°45'00.1" N, 7°03'42.0" E). The climatic condition at the study area are of Atlantic origin with temperatures at around 9.7°C and an annual precipitation of ca. 800 mm. The study site is located at an elevation of 72 m above sea level within a mosaic of farmland and forest patches. Oak and pine mixed forest surrounds the pond and eastwards an arable field borders (see Supplementary Fig. S1). The pond area varied largely and reached up to 180 m^2 at maximum and normally the volume ranged between 50–70 m^3. Rain is the only water source, whereas the groundwater level has no effect on the water regime of the pond. In nine (1999, 2001, 2003, 2008–2011, 2013 and 2015) out of 19 survey years the pond dried out by mid July. The pond contained diverse partly submerged vegetation including watercress (*Nasturtium officinale*), Narrow-fruited Water-starwort (*Callitriche palustris*) and floating sweetgrass (*Glyceria fluitans*). The pH scale measures averaged at 7.5.

Northern crested newts shared their breeding site with smooth (*Lissotriton vulgaris*) and Alpine newts (*Ichthyosaura alpestris*), whereas the latter were recorded in 1998 for the first time and resumed breeding in 2000 (von Bülow 2011). Also pool and edible frogs (*Pelophylax lessonae*/*P. esculentus*), some common frogs (*Rana temporaria*) and toads (*Bufo bufo*) were recorded, whereas the latter two anurans rarely used the pond as breeding site.

Capturing and identification techniques

Newts were captured with especially designed solid funnel traps (see Glandt 2000 and Supplementary Fig. S2). The traps consisted of an iron frame spanned with a durable fishing net (0.5 × 0.5 cm mesh width). The frame measured 52 × 30 × 30 cm, two large funnels (50 cm deep) were fixed on opposite sites (7 cm apart, outer funnel diameter 30 × 30 cm, inner diameter 9 × 5 cm). The trap was fixed via iron poles (15 cm long) into the substrate of the pond. The large size of the traps and the placement in shallower water of less than a meter allowed the newts rising to the surface in order to breathe. A lid made of an iron frame and spanned with the same fishing net closed the traps and prevented escape. The funnel traps were set for a total of 210 days (mean 11 ± 2 SD trapping days per year). Each trapping session started in the afternoon and the traps were controlled in the morning hours of the next day (exposure time was a maximum of 16 trapping hours). A set of seven traps was used for capturing newts. Monitoring usually started in late March and ended in mid July. If possible trapping continued throughout summer for checking the presence of larvae to verify the reproductive success and during winter in order to detect overwintering newts.

Estimation of population sizes and survival

In order to recognise individuals the belly pattern of each captured newt was photographed using a standard SLR camera (see e.g., Hagström 1973). Pictures were produced on photographic paper on which the date and individual number was noticed. A library was set which included 3,017 pictures of 1,868 individual newts by the end of the study in winter 2016. A capture and recapture program in order to estimate the yearly population size included all individuals. The total population size (N) of adults was estimated for each year by the triple catch method following Begon (1979, but see the procedure and equations in Donelly & Guyer 1994). Capture and marking were carried out on each trapping day from March until July, but in order to estimate the population size we used the capture/recapture data from three trapping days from April to mid-May, when we expected that the highest number of adult accumulated in the pond. Sampling efficiency was calculated in each study year by dividing the estimated population size by the total number of different individuals caught during that year (see also e.g., Arntzen & Teunis 1993, Baker 1999). These efficiency values were taken to obtain an estimate of the number of recaptures from previous years had sampling efficiency been 100%. This value in turn served to estimate the yearly survival rates for both adult males and females. In order to obtain a measure of the fluctuation of the population investigated we calculated the coefficient of variation (CV) for all yearly adult breeding population estimates. At the end we compared the CV of the study site to those of previous long-term studies throughout Europe using similar capture-recapture programs and capture methodologies.

Measurements of snout–vent lengths (in mm from tip of snout to posterior end of cloaca) of juvenile and subadult newts were obtained from digitalised photos following Kupfer (1999) using ImageJ v.1.47 (see Schneider et al. 2012) for Mac.

Results

Captures, dynamics and structure

Between 1998 and 2016, a total of 3,017 Northern crested newts were captured, representing 945 (51.1%) male, 841 (45.4%) female, 37 (2.0%) subadult and 45 (2.4%) juvenile individuals (see Supplementary Table S1).

Over the run of the study the estimated population size ranged from 20 to 279 adults (Fig. 1, CV = 61%). Population sizes were highest among the first four study years (227–279 adults) but afterwards decreased, circled around 144 adults between 2002 and 2010 but then dropped dramatically from 2010 to 2011. In the last six years of the study only a moderate number of adult newts (20 to 70) was estimated. In each survey year the proportion of individual adult newts ranged between 91 to 100% whereas only a small proportion of 2 to 10% consisted of young individuals of the age classes 1+ and 2+ (Fig. 2). Almost after each year of successful reproduction (verified from captures of late larval stages and efts = age class 0+) a small proportion of juveniles were recorded the following year (0.8 to 23.1%, see Fig. 2). In 2002 and 2008 no such juveniles were detected, but in the following 2003 and 2009 subadult newts (2+ age class) were detected.

The average ratio between individual females and males was 1.3 ± 0.3. In seven out of 19 years females outnumbered males but in nine years males were more abundant. In three years the sex ratio was equal. Successful reproduction detected through the presence of larvae only occurred in eleven years during the nineteen-year study period. There has been a reproduction failure in eight years including the consecutive years 2008 to 2011 (Fig. 2). In 2002 although larvae were found in July likely did not finalise metamorphosis because the pond dried out by the end of July (Fig. 2).

Two differently sized age classes of aquatic crested newts were detected along with adult males and females. Crested newts returning in the first year after metamorphosis (age class 1+) recorded in spring measured 38.62 ± 4.99 mm (n = 45, range 26.2–49.4 mm) in snout–vent-length, subadult externally sexable newts (age class 2+) after the second hibernation measured 54.52 ± 4.35 mm (n = 37, range 47.5–62.8 mm) in snout–vent-length.

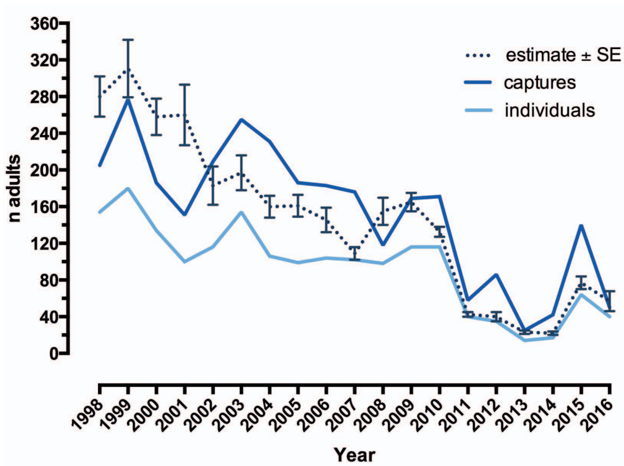

Figure 1. Estimated population size (± SE), numbers of adult individuals and captures of Northern crested newts *Triturus cristatus* at the study pond over 19 consecutive years (1998–2016).

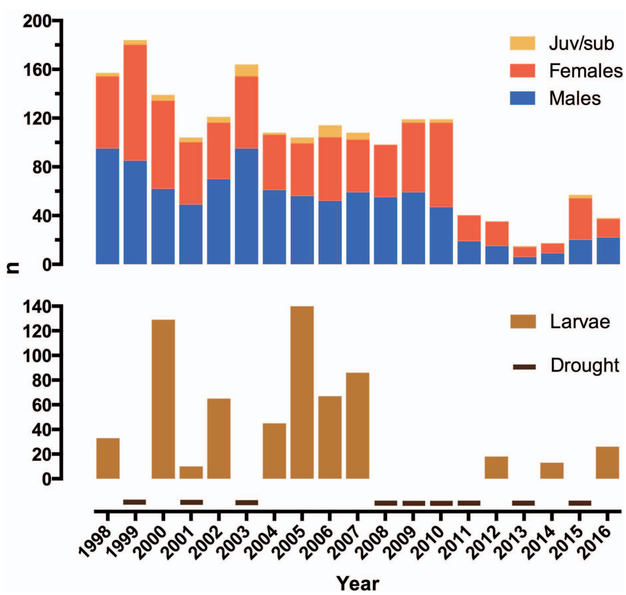

Figure 2. Population structure of individual Northern crested newts *Triturus cristatus* and numbers of larvae at the study pond over 19 consecutive years (1998–2016). Juveniles and subadult newts represent the age classes 1+ and 2+, years in which the pond dried out are indicated.

Survival

Estimates of survival in the first year after capture ranged between 27 to 90% in males and between 18 to 98% in females with no difference between the sexes (t = 0.7515, df = 34, p = 0.4575). Estimates of survival constantly decreased from the first to the tenth year after first capture for both sexes (Fig. 3). However some adult males were recaptured after ten (n = 7, 0.7% of male recaptures), eleven (n = 5, 0.5% of recaptures), twelve (n = 3, 0.3% of recaptures) and thirteen years (n = 2, 0.2% of recaptures) after their first capture. Only a single female was recaptured ten years after its first capture (0.2% of female recaptures).

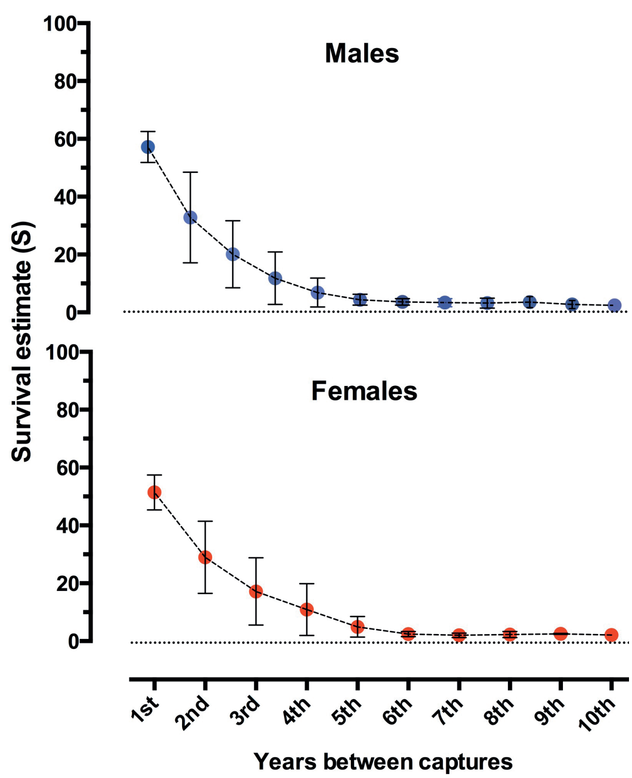

Figure 3. Summary of estimated annual survival (mean ± SE) of male and female Northern crested newts *Triturus cristatus* at the study pond over ten consecutive recapture years.

Table 1. Summary of long-term studies on the population dynamics of crested newts (genus *Triturus*). Type = population type: S = single population, M = metapopulation, N_i ± SD = average and SD of population estimates over n study yrs. Min–max = range of population estimates, CV = coefficient of variation (%), D = study duration, * population census obtained from number of individuals. Trend = summary of population dynamics, + = increasing, +/- = stable, - = decreasing.

Population	Type	N_i ± SD	min–max	CV	D	Trend	Source
Triturus cristatus							
Gothenburg	S	342 ± 104	230–500	30	5	+/-	Hagström (1979)
Greater Manchester I	S	29 ± 11	15–42	39	5	+/-	Orchard (2017)
Greater Manchester II	S	95 ± 23	70–124	45	4	+/-	Orchard (2017)
Lancashire	S	70 ± 32	39–110	24	4	-	Orchard (2017)
Buckinghamshire	S	113 ± 59	67–242	52	7	+	Baker (1999)
Kent	M	266 ± 122	95–440	46	12	-	Griffiths et al. (2010)
Calais	M	153 ± 109	53–346	71	6	-	Arntzen & Teunis (1993)
Münsterland	S	97 ± 10	89–108	10	4	+/-	Glandt (1982)
Dorsten	S	131 ± 81	20–279	61	19	-	This study
Krefeld I	M	158 ± 183	8–452	116	7	-	Drechsler et al. (2016)
Krefeld II	M	153 ± 69	60–252	45	6	-	Drechsler et al. (2016)
Merseburg	M	1359 ± 180	1231–1486	13	2	+/-	Meyer (2005)
Siegburg	M	29 ± 6	25–33	21	2	+/-	Wenzel et al. (1995)
Wachtberg	M	156 ± 25	136–186	16	3	+/-	Ortmann et al. (2006)
Triturus dobrogicus							
Vienna*	S	157 ± 34	52–210	50	9	-	Ellinger & Jehle (1997)
Triturus carnifex							
Grosetto	M	33 ± 9	9–43	33	20	+	Mori et al. (2017)

Survival estimates of males and females were positively related in the first ($p \leq 0.001$, $r^2 = 0.541$, $F = 18.89$), second ($p \leq 0.05$, $r^2 = 0.2844$, $F = 5.167$) and third ($p \leq 0.01$, $r^2 = 0.4555$, $F = 11.71$) after recapture, but not after the forth ($p = 0.0658$, $r^2 = 0.3619$, $F = 4.537$) and fifth year ($p = 0.9493$, $r^2 = 0.001$, $F = 0.004$) after their recapture.

Discussion

As expected the population of Northern crested newts at the study pond fluctuated markedly over the run of the study. Starting with a relatively high estimated number of adults the population dropped six-fold by the end of the study. When compared to other long-term population studies of crested newts (notably only three of them exceeded ten years) across Europe the dynamics of our study population appeared quite similar (Table 1) e.g., fluctuations in adult number of around 40 to 60% were also recorded in Buckinghamshire or Kent. In this respect the coefficient of variation appeared as a useful tool to describe the overall trends declines and increases in *Triturus* population dynamics as it directly allowed comparisons with other studies using a similar capture-recapture methodology. Interestingly higher fluctuations were only detected in population studies, which were carried out at least for longer than five years (Table 1).

In the case of the present study the population persisted throughout the nineteen study years despite unsuccessful breeding for many years in a row. Recruitment failures as a common character of crested newt population dynamics despite a yearly presence of breeding adults have been reported previously (e.g., Baker 1999, Griffiths et al. 2010, Kupfer & Kneitz 2000). For example although reproduction was verified in only five out of twelve study years a metapopulation of Northern crested newts in Southern England failed to extinct (Griffiths et al. 2010). However as demonstrated at the Krefeld study site (Table 1, Drechsler et al. 2016) consecutive recruitment failures caused by fish predation can lead to a rapid drop of adult population size near to local extinction in a short time scale (CV = 116%). Alternatively a constant recruitment over six consecutive years led to a threefold increase in adult population size (Kupfer & Kneitz 2000). Although multiple factors directly influence newt population dynamics we strongly believe that single and later consecutive (i.e., four years) recruitment failures directly caused the six-fold decline in adult population size at the study pond. Also previous studies on newt population dynamics identified pond-drying as the main driver for recruitment failures (Pechman et al. 1991, Semlitsch et al. 1996, Kupfer & Kneitz 2000, Jones et al. 2017). Occasional pond droughts could have positive effects on amphibian populations because aquatic predators such as fish can't establish (see also Kupfer & Kneitz 2000). Next to consecutive pond drying out events alterations of the adjacent terrestrial habitat could also contribute to amphibian population declines (e.g., Mcmenamin et al. 2008, Lau et al. 2017). However we exclude this threat in our interpretation because the terrestrial habitat consisting of mixed oak and pine forests have not been changed throughout the study.

Estimates of survival after the first year of capture varied between 18 to 98% for both sexes at the study site, whereas the overall survival estimates for both sexes between 1999 and 2016 averaged 26%. However some males and females were recaptured up to thirteen year after their first capture. Longevity of these long-term survivors was estimated up to 18 years (von Bülow 2014). Similar annual adult survival rates ranging between 30 to 100% have been estimated in previous long-term studies (e.g., Hagström 1979, Arntzen & Teunis 1993, Baker 1999). In our study we estimated that the chance of an adult surviving for one year was 54%; for two years 31% and still for four years was 11%. Thus, if no recruitment from larval age classes (0+) occurs during an extended drought period (in our case four years in a row caused by pond drying) the adult population still will likely have a moderate possibility of persisting.

Once more we could successfully demonstrate that the belly pattern of crested newts is a powerful tool to allow long-term individual recognition (see also Supplementary Fig. S3 as an example). Individual identification using non-invasive methodology is the backbone of capture and recapture programs. We think that only long-term studies such as the one presented herein (see also Taig-Johnston et al. 2017) sufficiently judge the persistence of local amphibian populations although long-term monitoring programs are personal intensive and financially expensive. Throughout Europe only studies lasting for at least five years sufficiently identified fluctuations (Table 1) and captured the long-term trend of the population. Therefore more long-term studies are urgently needed to assess how amphibian population dynamics are subject to the change of local environmental factors such rainfall or rely on demographical factors of the population itself.

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Supplementary material

3 Supplementary Figures and 1 Supplementary Table:

Figure S1. Image of the study pond viewed from the Eastern shore taken in April 2010.

Figure S2. Example of a robust funnel trap used for capturing amphibians at the study pond from 1998–2016.

Figure S3. Example of a male *Triturus cristatus* first captured at age 2+ (subadult) and recaptured as a mature male at ages of 3+, 5+ and 6+.

Table S1. Overview of numbers of individual Northern crested newts *Triturus cristatus* of all age classes registered at the study pond between 1998–2016.